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Invited paper

Recent progress in fiber-optic extrinsic Fabry–Perot interferometric sensors

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Abstract

Fiber-optic extrinsic Fabry–Perot (EFPI) sensors have been successfully used for a wide range of applications. The recent progress in EFPI sensors is reviewed in this paper. First, the optical amplification technology is adopted into the EFPI sensor system to enhance the interferometric signal considerably. Second, both spatial-frequency multiplexing and coarse-wavelength-division multiplexing technologies are demonstrated for multiplexing of a modified EFPI sensor called the Fizeau sensor. Finally, the EFPI sensor is integrated with other fiber-optic sensing elements to realize the measurement of multiple parameters, for example, the EFPI is integrated with the in-fiber Bragg-grating (FBG) or the long-period-fiber-grating (LPFG) to achieve simultaneous strain and temperature measurement. Furthermore, simultaneous measurement of displacement, transverse load, static strain, temperature, and vibration can be achieved by using the combination of EFPI/FBG/LPFG.

Keywords: Optical fiber sensors; Fiber-optic interferometric sensors; Fiber gratings; Optical amplification; Multiplexing; Multiple parameters measurement

1. Introduction

With the development of modern measurement technologies, fiber-optic sensors have attracted more and more attentions. Fiber-optic interferometric sensors are of importance as they have many advantages over conventional sensors, such as immunity to electromagnetic interference, capability of responding to a wide variety of measurands, very high resolution, high accuracy, small size, etc. Some of fiber-optic interferometric sensors have been successfully commercialized and widely used for health monitoring of composite materials, large civil engineering structures (e.g., bridges and dams), space aircrafts, and airplanes, etc., which would lead to the realization of so-called smart materials and structures [1]. The fiber-optic extrinsic Fabry–Perot interferometric (EFPI) sensor is one of the best candidates for such applications [2]. However, weak interferometric signal and difficulty in multiplexing are two major intrinsic drawbacks of EFPI sensors, limiting the applications of EFPI sensors considerably. In this paper, recent progress toward solving these two problems is described.

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2. Application of optical amplification to EFPI sensors [3]

As the reflectivity of the two fiber ends that form the EFPI cavity is very low, the optical power of reflected interferometric signal is normally quite small, which would result in poor S/N. In order to overcome the drawback of the EFPI, we propose a novel method base on optical amplification (OA) to enhance the signal level. The operating principle of such an EFPI/OA system is illustrated in Fig. 1. Light from a broadband ASE light source, consisting of an Er-doped fiber (EDF), a 1550/980 nm WDM coupler, an isolator and a pump laser, is launched into the EFPI. As show in the enlarged view of the EFPI, a lead-in fiber and a reflecting fiber were inserted into a hollow quartz tube with a length of ∼42 mm and an inner and outer diameter of ∼128 and ∼300 um, respectively. A certain air-gap of several hundred micrometers between the two cleaved fiber ends was used to form the EFPI cavity. The interferometric signal from the EFPI is amplified by the Er-doped fiber amplifier (EDFA) and then detected by an optical spectrum analyzer (OSA). Its typical optical spectrum is shown in Fig. 2. As can be seen from Fig. 2, the optical power output of the EFPI/OA system is in the level of microwatt. As a comparison, the optical power output of the EFPI sensor system without OA is shown

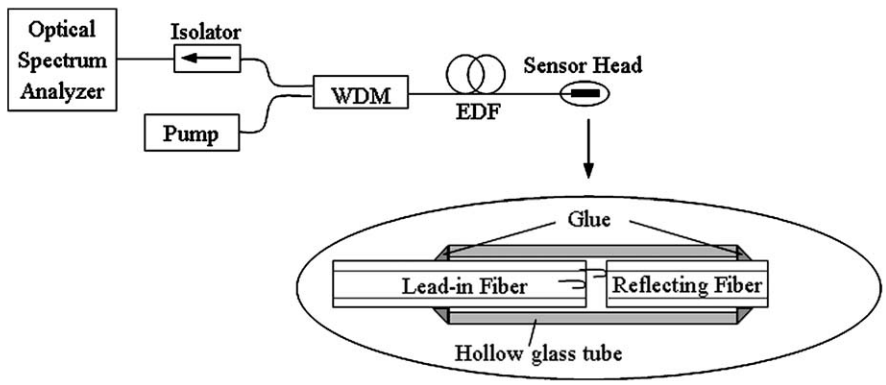

Fig. 1. EFPI sensor system based on optical amplification.

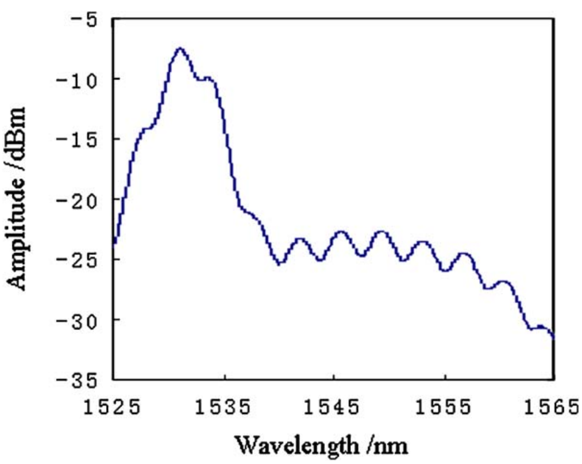

Fig. 2. Reflective spectrum of the sensor system with optical amplification.

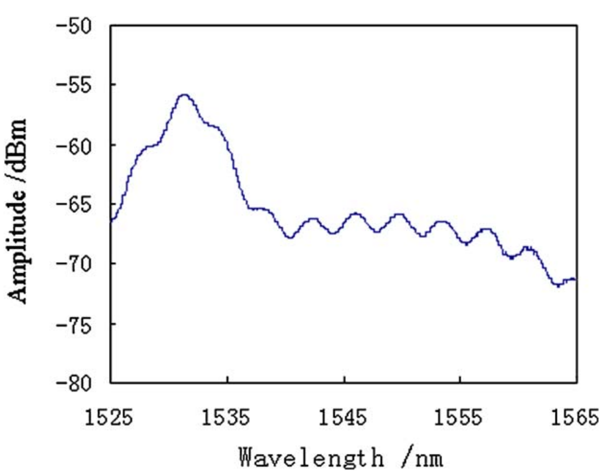

Fig. 3. Reflective spectrum of the sensor system without optical amplification.

in Fig. 3. It can be seen that the signal level is improved by 43 dB!

In order to evaluate the performance of the EFPI/OA system, a strain experiment is carried out. The experimental setup is shown in Fig. 1 where both the EFPI and an electrical strain gauge are mounted on a steel cantilever. When a load is applied to the end of the cantilever, the strain due to the deflection of the cantilever is measured by using the EFPI and the strain gauge, respectively. Since the spectrum of the interferometric signal within the wavelength range 1540–1560 nm is relatively flat (gain flatness is normally less than 3 dB), the interferometric fringes within 1540–1560 nm are used to determine the absolute cavity length, although the spectrum of the signal can be flatten using a gain equalizer such that a wider spectral range can be used to obtain more fringes and hence better measurement accuracy. From the experimental, a strain accuracy of $\sim\pm 5$ μm has been obtained by the use of the EFPI/OA system, which is twice better than that of the EFPI without optical amplification under the same experimental conditions reported by the authors previously.

It is anticipated that such an EFPI/OA sensor system could be used for a wide range of applications, in particular, for those applications where remote monitoring with a very long distance is essential. Also, it can reduce the requirements for detection and the complexity for signal processing in practice when compared to conventional EFPI systems. In addition, it can be employed for multipoint measurement by means of spatial division multiplexing due to the substantial improvement in signal level.

3. Multiplexing of EFPI sensors

3.1. Spatial-frequency-multiplexing (SFDM) of Fizeau sensors [4]

EFPI sensor is difficult for multiplexing due to limited cavity length. In order to overcome the disadvantage, we propose a novel method. This method employs a Fizeau cavity to replace the EFPI structure, which allows the cavity length to be enlarged up to several mm without obvious signal degradation. This will make the multiplexing of more than ten sensors feasible. Figure 4 illustrates the configuration of the Fizeau sensor system. The reflectivities of the lead-in fiber and the reflecting fiber are ∼4 and ∼95%, respectively. As the reflectivity of the two fiber ends is quite different and the intensity distribution of the interferometric signal is also different from that of a F–P cavity, we called it Fizeau cavity in order to distinguish it from the conventional F–P cavity. The interferometric signal of the Fizeau cavity is amplified by an EDFA and then detected by an OSA. As the reflectivity of the lead-in fiber is only 4%, the multibeam interference in the cavity could be simplified as a two-beam interference approximately. Since the probability of